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-	0	((345/848).CCLS.) and (link same non-link same 3D)	USPAT	2003/12/04 16:28
-	0	((345/848).CCLS.) and (link same non-link same dimension)	USPAT	2003/12/04 16:29
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-	0	((345/848).CCLS.) and (link same non-link)	USPAT	2003/12/04 16:29
-	76	((345/848).CCLS.) and (3D or 3-dimensional)	USPAT	2003/12/04 16:40
-	33	((345/848).CCLS.) and (3D or 3-dimensional) and link	USPAT	2003/12/05 15:23
-	1	6346956.pn. and room	USPAT	2003/12/05 15:24
-	0	6346956.pn. and distance	USPAT	2003/12/05 15:24
-	1	6346956.pn. and space	USPAT	2003/12/05 15:35
-	0	6346956.pn. and priority	USPAT	2003/12/05 17:49
-	1	6346956.pn. and anchor	USPAT	2003/12/08 12:18
-	1	6346956.pn. and coordinate	USPAT	2003/12/08 12:26
-	1	5841440.pn.	USPAT	2003/12/08 12:26

US005841440A

United States Patent [19]

Guha

[11] Patent Number: 5,841,440

[45] Date of Patent: Nov. 24, 1998

[54] **SYSTEM AND METHOD FOR USING A POINTING DEVICE TO INDICATE MOVEMENT THROUGH THREE-DIMENSIONAL SPACE**

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[73] Assignee: **Apple Computer, Inc.**, Cupertino, Calif.

[21] Appl. No.: **767,693**

[22] Filed: **Dec. 17, 1996**

[51] **Int. Cl.**[6] **G06T 15/00**

[52] **U.S. Cl.** **345/419**

[58] **Field of Search** 345/419, 420, 345/421, 422, 423, 424

[56] **References Cited**

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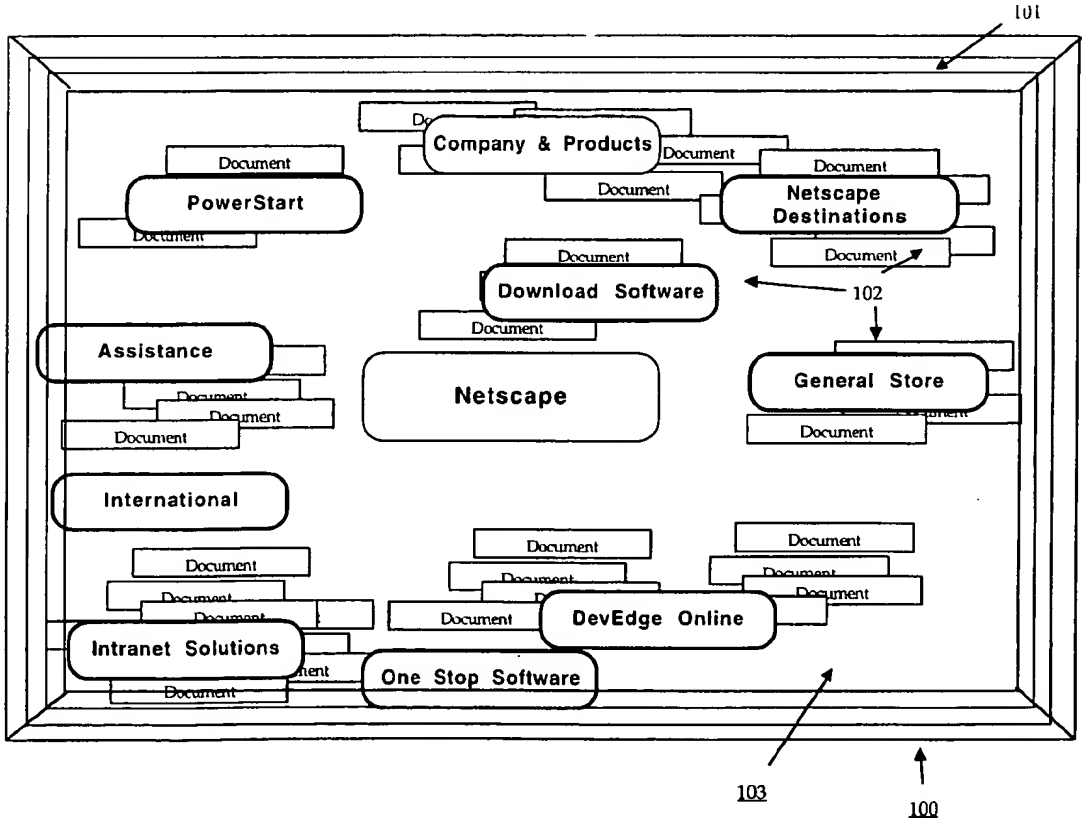
Primary Examiner—Cliff N. Vo

Attorney, Agent, or Firm—Fenwick & West LLP

[57] **ABSTRACT**

A system and method of displaying movement in three-dimensional space in response to input from a conventional two-dimensional pointing device such as a mouse or trackball. The three-dimensional space is projected onto a two-dimensional plane for display in a window on a display screen. A viewpoint position, which may be the center of the window, is defined as the current virtual position of the "camera" through which the three-dimensional space is viewed. The user manipulates an on-screen cursor across the window to specify a direction of movement in the two-dimensional plane. A three-dimensional direction of movement is derived from the user's input by defining a sphere having a center corresponding to a the center of the two-dimensional plane, and determining the intersection of a line perpendicular to the plane at the cursor location with the surface of the sphere. The direction of movement is then defined as a vector from the origin to the determined intersection. The system and method distinguish between navigation commands and object manipulation commands according to the timing and context of the commands.

32 Claims, 9 Drawing Sheets



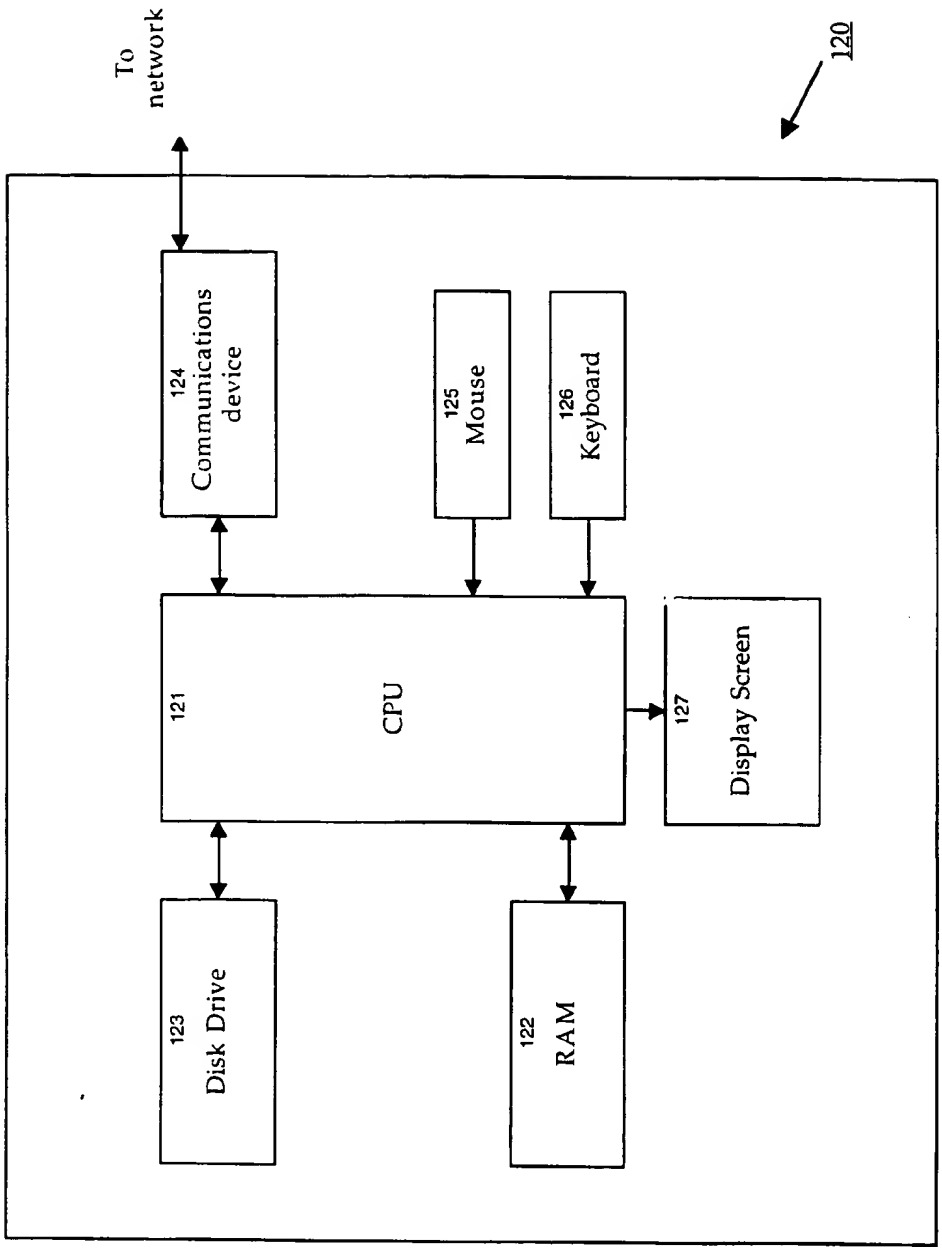

To network
120
124 Communications device
125 Mouse
126 Keyboard
121 CPU
127 Display Screen
123 Disk Drive
122 RAM

FIGURE 1A

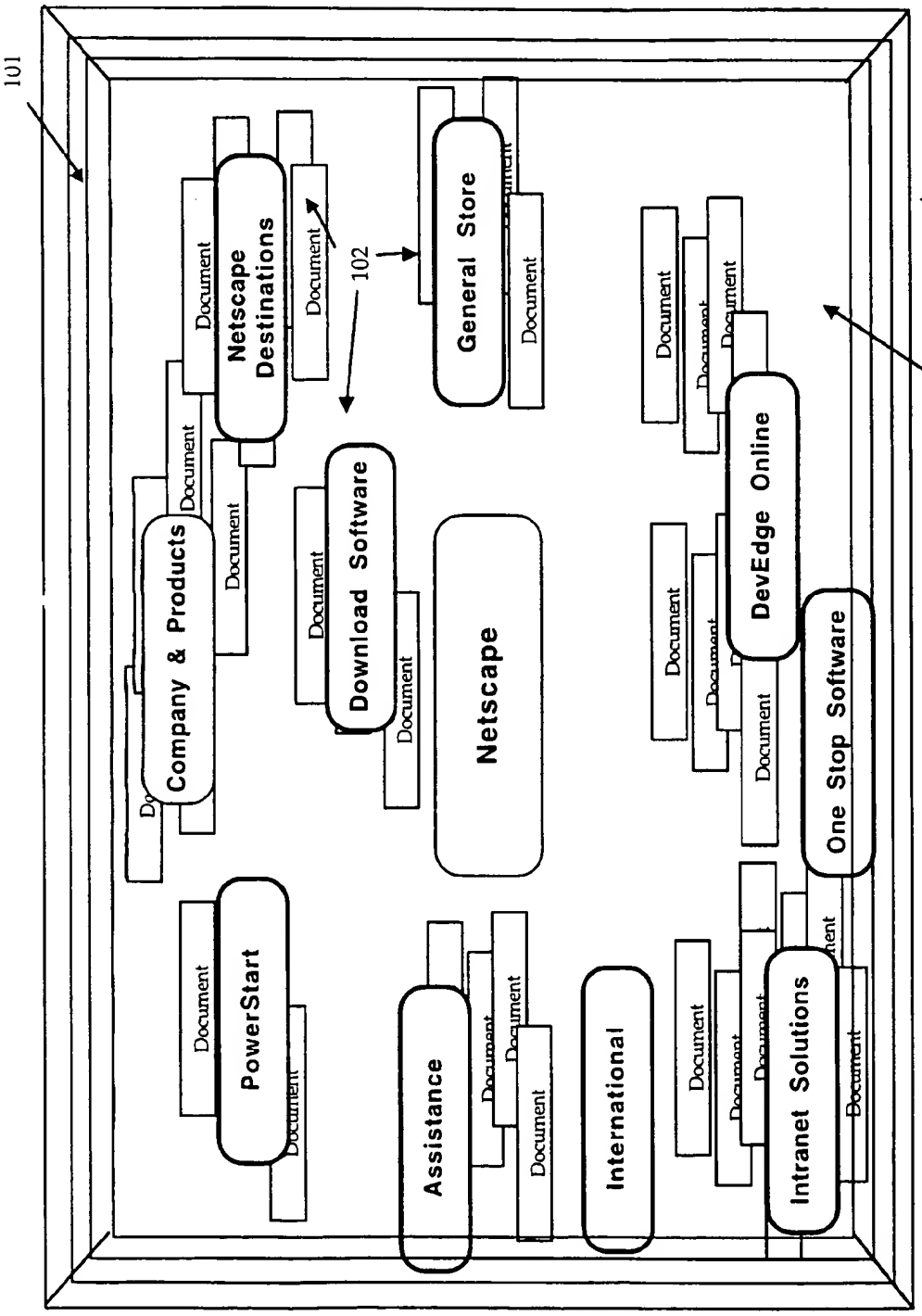

101
100
102
103
Netscape Destinations
General Store
Company & Products
Download Software
Netscape
DevEdge Online
One Stop Software
PowerStart
Assistance
International
Intranet Solutions
Document

FIGURE 1B

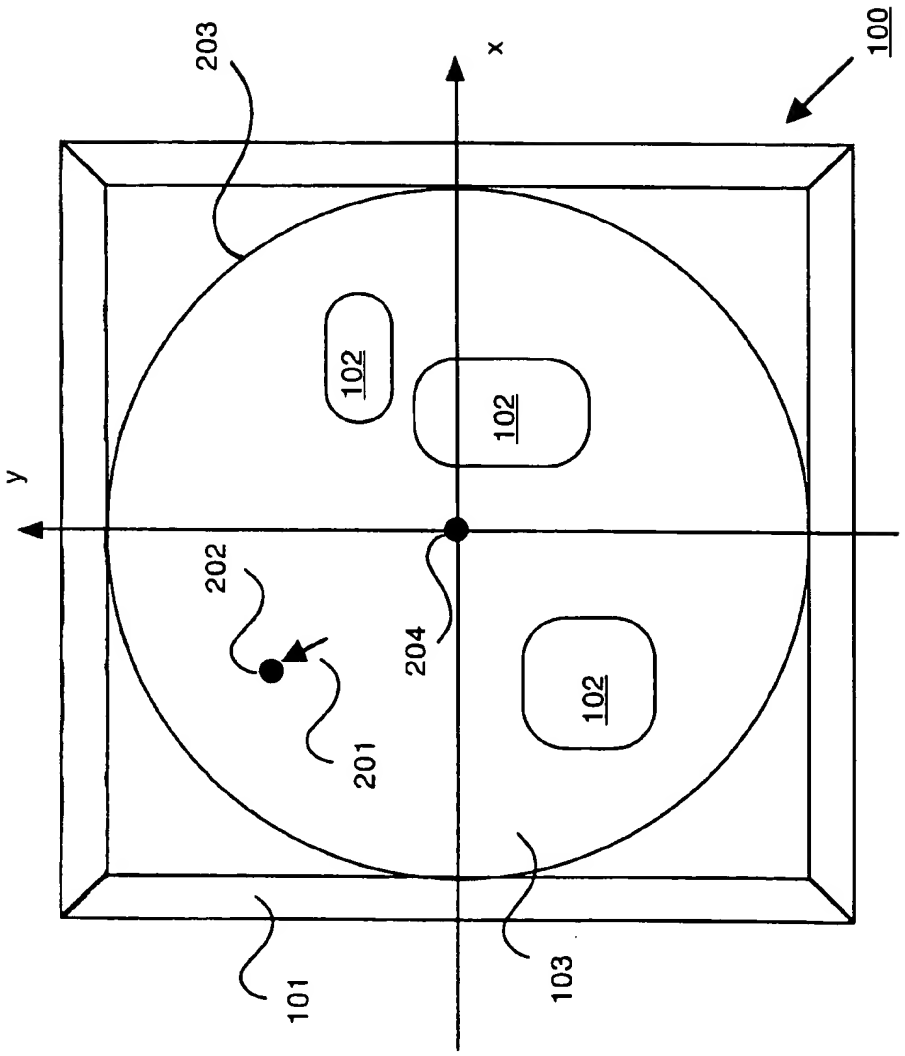


FIGURE 2

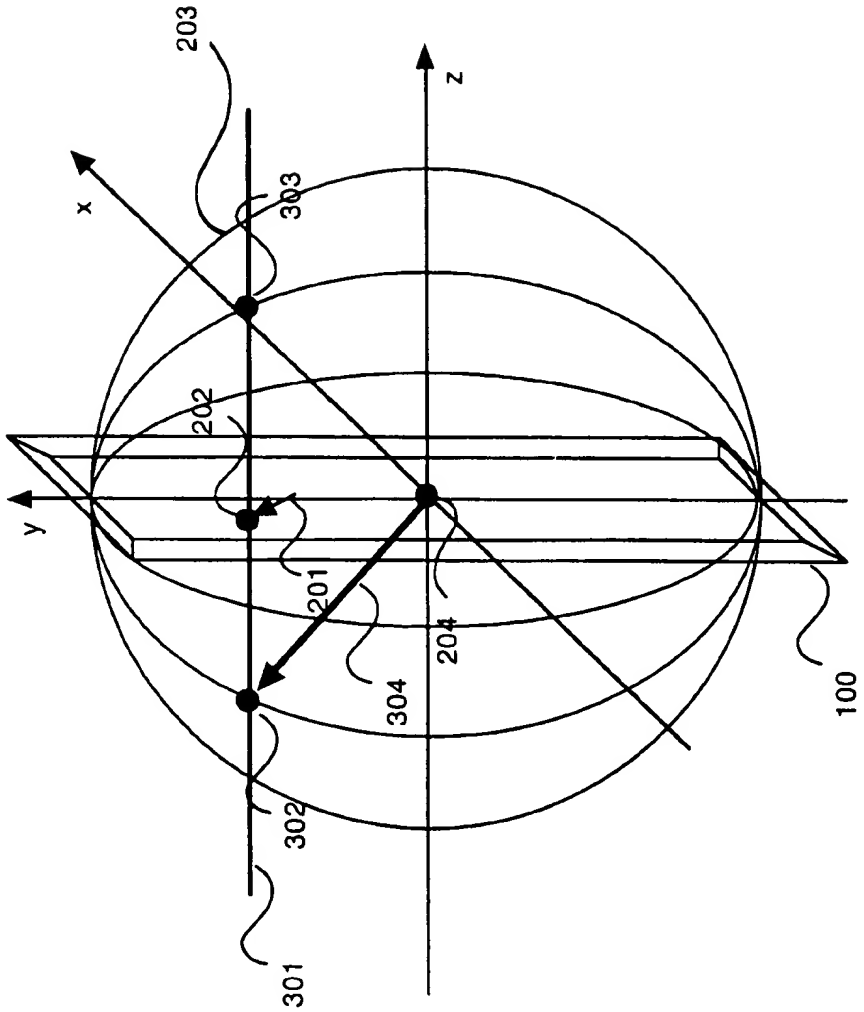


FIGURE 3

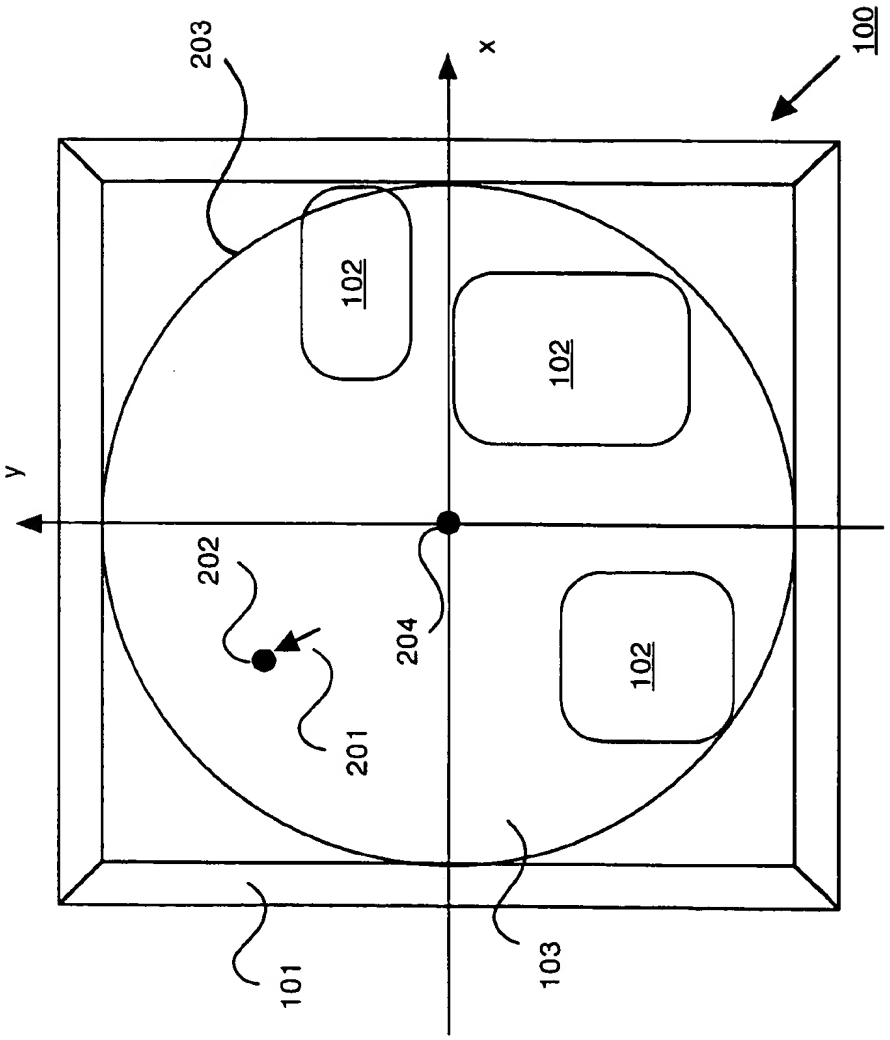


FIGURE 4

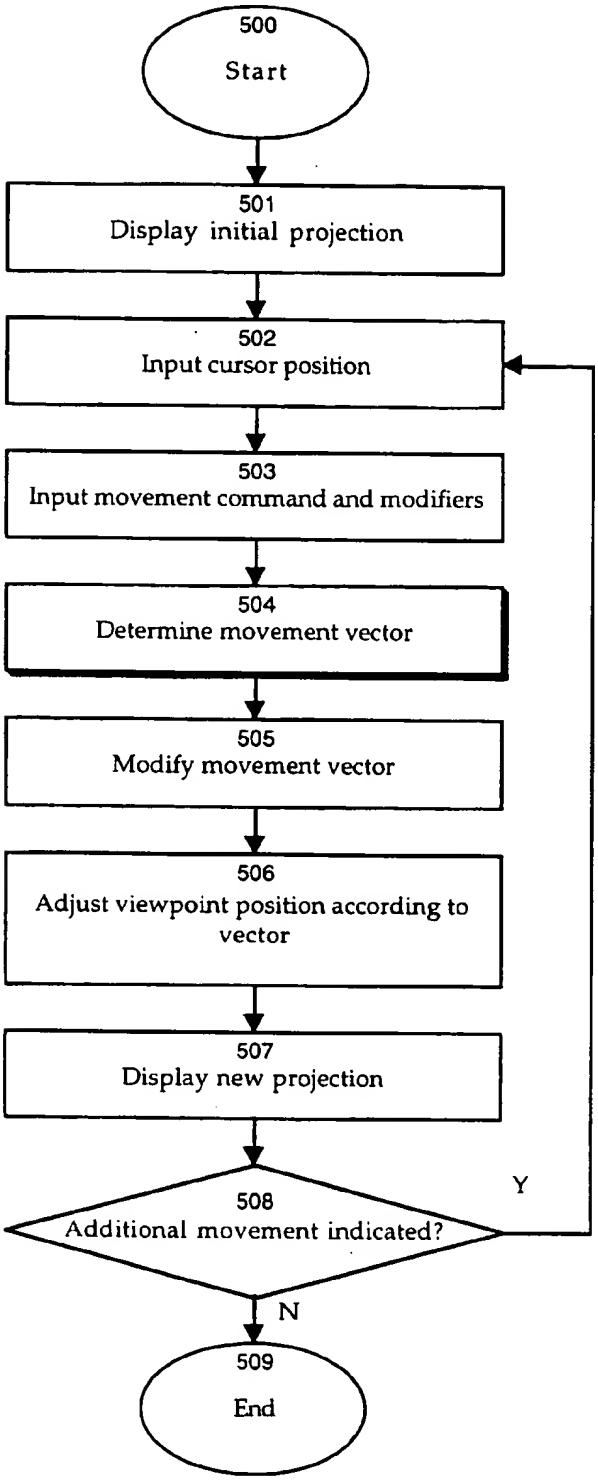

500
Start
501
Display initial projection
502
Input cursor position
503
Input movement command and modifiers
504
Determine movement vector
505
Modify movement vector
506
Adjust viewpoint position according to vector
507
Display new projection
508
Additional movement indicated?
Y
N
509
End

FIGURE 5

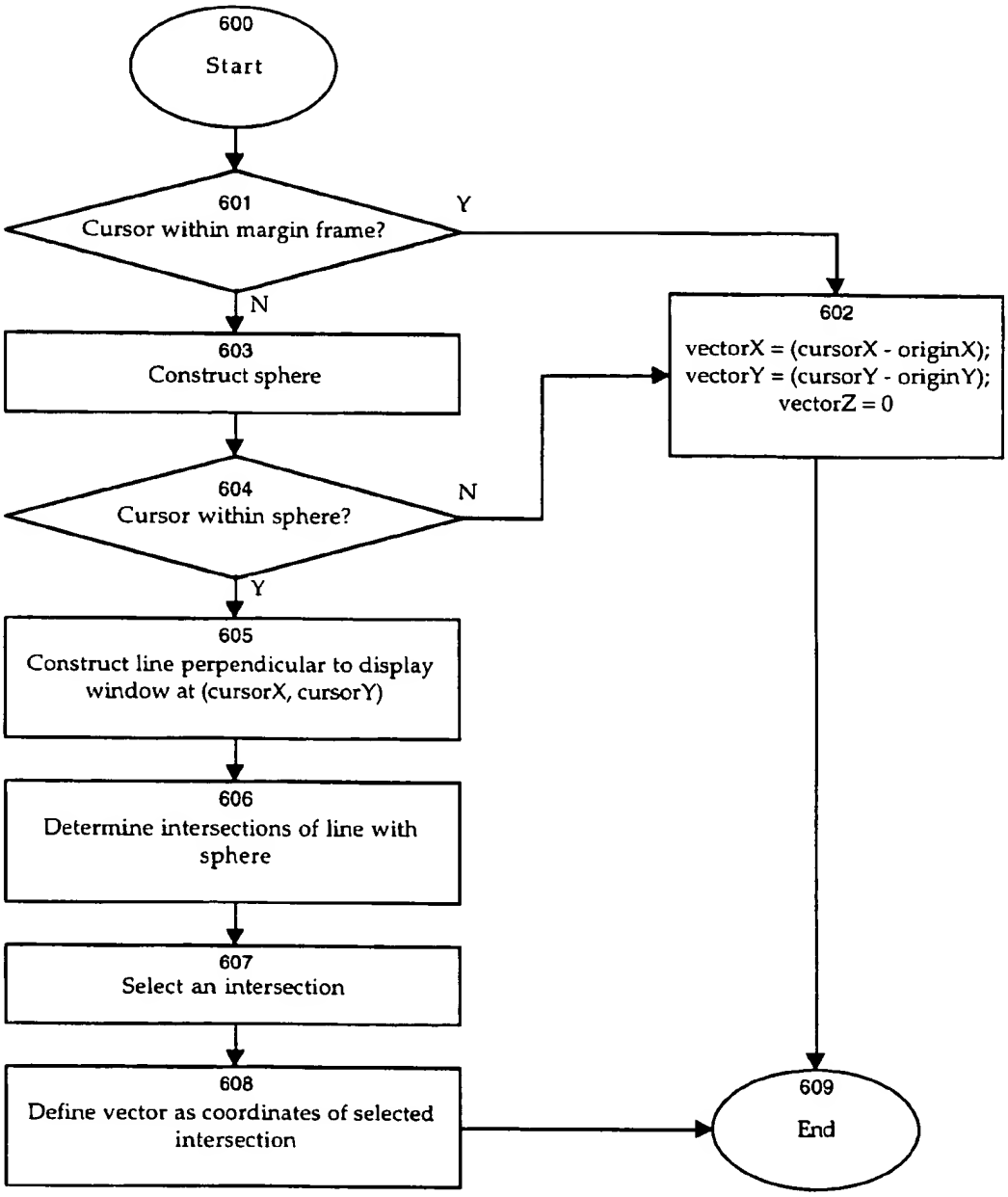

600
Start
601
Cursor within margin frame?
Y
N
602
vectorX = (cursorX - originX);
vectorY = (cursorY - originY);
vectorZ = 0
603
Construct sphere
604
Cursor within sphere?
N
Y
605
Construct line perpendicular to display window at (cursorX, cursorY)
606
Determine intersections of line with sphere
607
Select an intersection
608
Define vector as coordinates of selected intersection
609
End

FIGURE 6

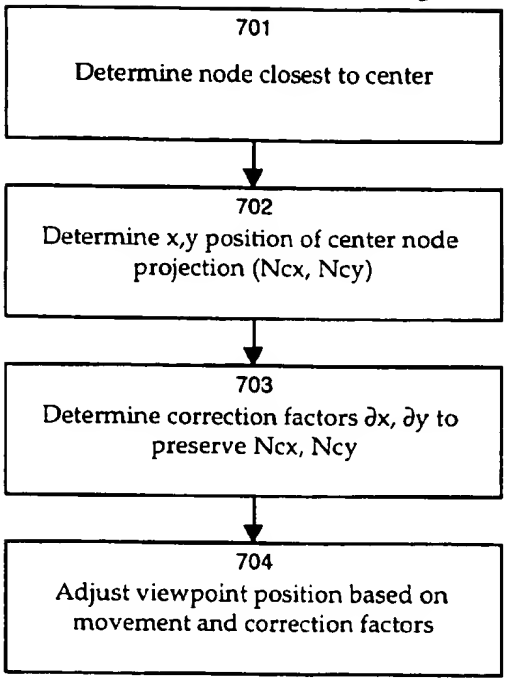

701
Determine node closest to center
702
Determine x,y position of center node projection (Ncx, Ncy)
703
Determine correction factors ∂x, ∂y to preserve Ncx, Ncy
704
Adjust viewpoint position based on movement and correction factors

FIGURE 7

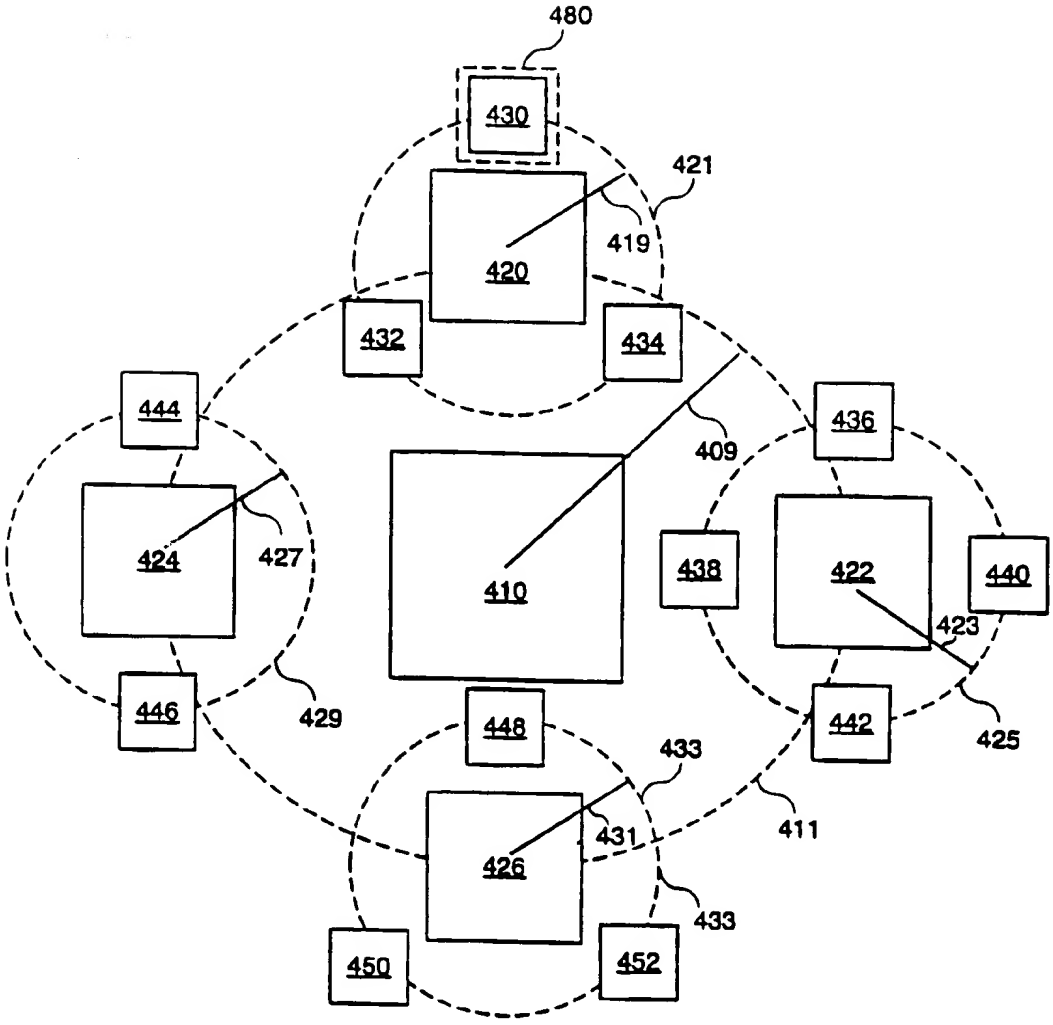

480
430
421
419
420
432
434
444
436
409
424
427
410
438
422
440
423
446
429
448
442
425
433
431
426
411
433
450
452

FIGURE 8

SYSTEM AND METHOD FOR USING A POINTING DEVICE TO INDICATE MOVEMENT THROUGH THREE-DIMENSIONAL SPACE

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to U.S. patent application Ser. No. 08/744,611 for "Method, Apparatus and Computer Program Products to Simulate the Display of Objects in Three Dimensions", by Ramanathan V. Guha, filed Nov. 6, 1996, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to navigation in a virtual three-dimensional space, and more particularly to a system and method for indicating and displaying movement through three-dimensional space.

2. Description of Background Art

Many computer software applications simulate movement through a virtual three-dimensional environment, or space. The three-dimensional space typically contains a plurality of objects, each having particular visual characteristics and a defined position in three-dimensional space. A two-dimensional projection of the three-dimensional space is displayed in a window on a display screen, including projections of all or some of the objects.

The techniques for projecting three-dimensional space onto a two-dimensional display window are generally known in the art. See, for example, J. Foley et al., *Computer Graphics: Principles and Practice,* 2 d. ed., Addison-Wesley, 1990. Typically, a viewpoint position and orientation are established within the three-dimensional space, specifying the position and orientation of a virtual "camera" through which the user views the environment. Objects within a viewable area of the three-dimensional space are projected onto the display window by scaling objects according to their distance from the viewpoint position, so that more distant objects are shown smaller than closer ones. Other techniques may also be used to represent relative detail, such as changes in color, level of detail, and the like.

Many such conventional systems provide mechanisms by which a user may change the viewpoint position. By successively redrawing objects according to changed viewpoint positions, the system can simulate movement through the three-dimensional space.

In order to effectively provide such simulated three-dimensional movement, the system must be capable of accepting input from a user specifying desired directions and speeds of movement. Conventional, commonly-used input devices are typically capable of indicating movement on a computer display in only two dimensions. More complex pointing devices such as virtual reality gloves are available but tend to be more expensive than commonly-available devices such as mice or trackballs.

In many systems, direct manipulation of on-screen objects is performed by positioning a cursor under the control of an input device such as a mouse or trackball and clicking a button. If the same input device is employed for both manipulation and navigation, ambiguity may result when the user clicks the button. In other words, it may not be clear whether the user wishes to manipulate an on-screen object or to move in the direction pointed. Modifier keys or multiple mouse buttons may be employed, but these techniques introduce complexity, increase learning time and confusion, and detract from the intuitive nature of the interface.

What is needed is a system and method for a user to indicate movement in three-dimensional space in an intuitive manner using a conventional, commonly available input device such as a mouse or joystick. In addition, what is needed is a system and method for distinguishing between navigation and manipulation commands in a manner that does not significantly increase the complexity of the system from the user's point of view.

SUMMARY OF THE INVENTION

The present invention provides a system and method of displaying movement in three-dimensional space in response to input from a conventional two-dimensional pointing device such as a mouse or trackball.

The three-dimensional space is projected onto a two-dimensional plane for display in a window on a display screen. A viewpoint position, which may be the center of the window, is defined as the current virtual position of the "camera" through which the three-dimensional space is viewed. Three axes may thus be defined: a horizontal x-axis and a vertical y-axis, both parallel to the display window, and a z-axis representing movement perpendicular to the display window. The viewpoint position is located at the origin of the axes.

The user manipulates an on-screen cursor across the window to specify a direction of movement in the x- and y-axes. Keyboard keys or mouse buttons are pressed to specify "forward" or "backward" movement (corresponding to the positive or negative direction of the z-axis).

A direction of movement is derived from the user's input as follows. A sphere is defined having a center corresponding to the origin of the axes and thus corresponding to the viewpoint position. A line is defined which is perpendicular to the display window and which intersects the plane of the window at the coordinates specified by the position of the on-screen cursor. If the cursor position lies within the radius of the circle defined by the sphere's projection in the display window, the line will intersect the surface of the sphere at two points, one representing movement into the screen (corresponding to "forward" movement) and one representing movement out of the screen (corresponding to "backward" movement). One of the two points is selected based on the user's keyboard or mouse button input. The direction of movement is then defined as a vector from the origin to the selected point on the sphere.

If the cursor position lies at the edge of the circle defined by the sphere's projection, or outside the bounds of the circle, the direction of movement is defined as a vector from the origin to the x- and y-coordinates of the cursor position, with a z-component of zero. This represents movement along the plane of projection.

The display is then adjusted to reflect movement in the direction of the defined vector by changing the coordinates of the viewpoint position and generating a new two-dimensional projection. In accordance with user input, the speed of movement may be changed by scaling the vector by a specified factor. The cursor may be moved as the display is adjusted, resulting in corresponding adjustment of the movement vector using the technique described above.

If a non-linear projection technique is employed, as described in related U.S. patent application Ser. No. 08/744,611 for "Method, Apparatus and Computer Program Products to Simulate the Display of Objects in Three

Dimensions", the viewpoint position is adjusted to compensate for the non-linearity and to preserve the illusion of movement in the desired direction.

In addition, the three-dimensional navigation scheme of the present invention may be employed in an application wherein the user is able to manipulate objects within the three-dimensional environment. For example, the user may wish to move or activate buttons or icons within the window. Such manipulation is often performed using the same input device, such as a mouse or trackball, and the same keys or buttons, as is used for navigation. In order to preserve a simple and intuitive user interface, one embodiment of the present invention provides a mechanism for distinguishing among the user's desired actions based on the context and nature of the user input. For example, if the user clicks a mouse button on an area of the screen and holds down the button for some period of time (such as for example 0.5 seconds) without substantially moving the cursor, this is interpreted as a navigation command. However, if the user clicks the mouse button and immediately starts moving, this is interpreted as an object manipulation command specifying movement of the object under the cursor (if any). If no object is under the cursor, this command is interpreted as navigation. Thus, the intended action is determined based on the context of the user's input.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a block diagram of a hardware architecture for practicing the present invention.

FIG. 1B is an example of a screen shot showing a window containing a two-dimensional projection of a three-dimensional space.

FIG. **2** is a front view of a window containing a two-dimensional projection of a three-dimensional space.

FIG. **3** is a side view of a window containing a two-dimensional projection of a three-dimensional space.

FIG. **4** is a front view of a window containing a two-dimensional projection of a three-dimensional space, after the viewpoint position has moved.

FIG. **5** is a flowchart of a method of indicating and displaying movement through three-dimensional space according to the present invention.

FIG. **6** is a flowchart of a method of determining a movement vector according to the present invention.

FIG. **7** is a flowchart of a method of correcting viewpoint position for nonlinear movement according to the present invention.

FIG. **8** is a block diagram of objects displayed in three planes according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. **1A**, there is shown a block diagram of a hardware configuration for practicing the present invention. In one embodiment, the present invention is implemented as software running on a conventional personal computer such as an Apple® Macintosh® computer. Thus, the hardware architecture of system **120** as shown in FIG. **1A** may be implemented as a combination of components of such a computer, though other implementations may also be used. Central processing unit (CPU) **121** executes software instructions and interacts with other components to perform the techniques of the present invention. Random-access memory (RAM) **122** stores software instructions to be executed by CPU **121**, and may store other data to act as a workspace in the implementation of the present invention, including for example, representations of object characteristics and positions in three-dimensional space. Disk drive **123** provides long-term storage of data and software programs. Input devices such as mouse **125** and keyboard **126** facilitate user control of the operation of system **120**, including navigation through a simulated three-dimensional environment. Display screen **127** is an output device such as a cathode-ray tube for the display of two-dimensional projections of the three-dimensional space under the control of CPU **121**. System **120** may also include communications device **124** such as, for example, a modem for connection to a computer network such as the Internet.

Referring now to FIG. **1B**, there is shown a sample screen shot of a window **100** containing a two-dimensional projection **103** of a three-dimensional space. In one embodiment, window **100** is displayed on display screen **127**. Objects **102** are located at various positions in the three-dimensional space and are projected onto window **100** using techniques that are known in the art. In the example shown, the impression of depth is created by overlaying closer objects **102** on top of objects **102** that are farther away. In addition, closer objects **102** are displayed at a larger size than objects **102** that are farther away. Finally, the example of FIG. **1B** differentiates among several distance planes by the use of distinct colors. Other visual cues representing relative distance may also be used. In one embodiment, the projection is performed using adjusted spread between objects **102** as described in related application Ser. No. 08/744,611. Margin frame **101** provides a navigational tool for moving parallel to the plane of the projection, as will be described in more detail below.

In one embodiment, objects **102** represent documents and directories that may be manipulated, opened, or activated by the user. In one embodiment, system **120** is connected to a network such as the Internet, and some objects **102** may represent web pages or other documents accessible by system **120** over the network via communications device **124**.

The present invention is directed towards a system and method of navigating through a three-dimensional space as exemplified in FIG. **1B**.

Referring now to FIG. **5**, there is shown a flowchart of a method of indicating and displaying movement through three-dimensional space according to the present invention. An initial viewpoint position is established. Based on this viewpoint position, system **120** generates and displays **501** an initial two-dimensional projection of a three-dimensional space in a window **100** on display screen **127**.

In one embodiment, such display is generated by conventional projection methods. In another embodiment, the two-dimensional projection is generated in a nonlinear manner, as described in related U.S. patent application Ser. No. 08/744,611. Related U.S. patent application Ser. No. 08/744,611 describes a hierarchical arrangement of data, with each object being assigned a level in the hierarchy. An object is related to one or more objects on the level beneath it by being a parent of such lower level objects, with each of the lower level objects having a common parent being siblings to one another. A two-dimensional projection of a three-dimensional space allows the user to view hierarchically arranged data by displaying objects at each level in a separate plane, with each plane being positioned at a different distance (z-value) from the user. The relationships among sibling objects and between child and parent objects

may be graphically represented by clustering the child objects around the projection of their parent on the plan directly behind the plane containing the parent. However, as the plane containing the child objects approaches the window, it is desirable to ensure adequate space between the objects to allow the user to maneuver among the objects and to allow room to display the descendants of the child objects in an uncluttered way. Thus, the related patent application describes a technique of adjusting the spacing between objects differently from the size of the objects as the user navigates in three-dimensional space. In effect, as the user navigates closer to a set of objects, the objects appear to spread apart from one another more quickly than they are growing in size. As objects approach, the spread between two objects, representing the distance between their projections, is determined using the prior spread, the increase in size of the objects, and a scaling factor or scaling factor function.

One example of a scaling factor function is:

$$f(n) = \frac{K}{l} \times \sum_{m=1}^{n} \frac{1}{\sqrt{b_m}} \quad \text{(Eq. 1)}$$

where:

K is a constant;

l=the distance between the projection window and the first visible plane;

n=the number of planes between the projection window and the plane of the object in question;

b_m=1+the number of sibling objects of the object or its ancestor in the mth displayed plane.

Referring now to FIG. **8**, there is shown a sample two-dimensional projection of a hierarchical arrangement of objects in three-dimensional space. Objects **410**, **420**, **422**, **424**, **426**, **430**, **432**, **434**, **436**, **438**, **440**, **442**, **444**, **446**, **448**, **450**, and **452** are displayed on three planes. Objects **420**, **422**, **424**, **426**, all displayed on plane **2**, are arranged in a circle **411** having a radius **409** around their parent object **410**, displayed on plane **1**. Child objects **430**, **432**, **434**, all displayed on plane **3**, are arranged in a circle **421** having a spread equal to radius **419** around their parent object **420**. Other objects **436**, **438**, **440**, **442**, **444**, **446**, **448**, **450**, **452**, all displayed on plane **3**, are arranged in circles **425**, **429**, **433** having radii **423**, **427**, **431** around parent objects **422**, **424**, **426**, as shown in the Figure. The spread between each of the child objects **420**, **422**, **424**, **426**, **430**, **432**, **434**, **436**, **438**, **440**, **442**, **444**, **446**, **448**, **450**, **452** and its parent is equal to the radius of the circle **411**, **421**, **425**, **427**, **429** on which the object is displayed.

Thus, for circle **425**, b_1=1 (1+0 sibling objects of object **410**), b_2=4 (1+3 sibling objects of object **422**), and b_3=4 (1+3 sibling objects for each object **436**, **438**, **440**, **442**). The scaling factor given by Eq. 1 will thus be (K/l)×1/1×1/2×1/2, or (K/l)×1/4, or 0.25(K/l). By contrast, the scaling factor for circle **429** is 0.35(K/l). The displayed radius of each circle is divided by the scaling factor, so that circles on which more objects are placed grow larger than circles on which fewer objects are placed.

The position of a given object in the two-dimensional projection is determined by reference to the position of its parent object using the equations:

$$x_{projected} = (x_1 - x_u)f(1) + \sum_{m=2}^{n} x_m f(m) \quad \text{(Eq. 2)}$$

-continued

$$y_{projected} = (y_1 - y_u)f(1) + \sum_{m=2}^{n} y_m f(m) \quad \text{(Eq. 3)}$$

where:

$x_{projected}$, $y_{projected}$ represent the projected coordinates of the object in window **100**;

x_1, y_1 are the x and y coordinates of the highest-level visible ancestor of the object;

x_u y_u are the x and y coordinates of the viewpoint position;

f( ) is the scaling function, for example as described in Eq. 1;

n is the number of planes between the projection plane and the plane containing the object, plus 1; and

x_m, y_m are the x and y coordinates of the ancestor of the object on plane m, relative to the x and y coordinates of the ancestor's immediate parent.

Referring now also to FIG. **2**, there is shown a front view of a simplified representation of a window **100** containing a two-dimensional projection **103** of a three-dimensional space as displayed **501** by system **120**. In one embodiment of the present invention, the three-dimensional space can be described in terms of a coordinate system including x- and y-axes as shown, along with a z-axis (not shown) which extends in a direction perpendicular to the plane of window **100**. All three axes have an origin **204** which corresponds to the center of window **100**. In one embodiment, origin **204** is also the viewpoint for the two-dimensional projection. Other coordinate schemes and orientations may be used, including, for example, placing the viewpoint at some non-zero position along the z-axis. In one embodiment, such as that illustrated in FIG. **1**, the location of origin **204** is not displayed on the screen.

Referring again to FIG. **5**, system **120** accepts **502** user input from mouse **125** or keyboard **126** specifying a cursor position in window **100**. Cursor **201** is a movable pointer that is controlled by the user. In one embodiment, the user manipulates a pointing device such as mouse **125** or trackball (not shown) to control the position of cursor **201** within window **100**, although other mechanisms such as a keyboard **126** may be used. The user selects a desired direction for movement by positioning cursor **201**. The user then initiates movement by providing a movement command **503**. In one embodiment, such movement command is provided by clicking and holding down a mouse button. Alternatively, such movement command may be provided via keyboard **126**. Point **202** in FIG. **2** indicates the position of cursor **201** at the moment the user initiates movement.

In one embodiment, the user may further specify the direction and speed of desired movement via modifier keys, such as the following:

Forward movement ("into" the screen): hold mouse button down

Backward movement ("out of" the screen): hold Command or Control key on keyboard **126** while holding mouse button down, or hold second mouse button down

Accelerated movement: hold Shift key while performing other commands

Highly accelerated movement: hold Control or Alt key while performing other commands

Once the movement command has been provided by the user, the system of the present invention determines **504** a movement vector representing a direction of movement in three-dimensional space. The movement vector is a three-dimensional vector specifying a direction and magnitude of movement.

Referring now to FIG. **6**, there is shown a flowchart of a method of determining **504** a movement vector according to

one embodiment of the present invention. Referring also to FIG. **3**, there is shown a side view of the simplified projection shown in FIG. **2**, with additional constructions illustrating the method of FIG. **6**. As described previously, the three-dimensional movement vector is determined based on the two-dimensional position of cursor **201**. If cursor **201** is within margin frame **101** at the time the movement command is initiated, the movement vector is assigned **602** a z-value of zero, so that the viewpoint position will move parallel to the plane of the projection. Thus, the user can specify horizontal, vertical, or diagonal movement in the x-y plane if desired, by positioning cursor **201** in the appropriate location in within margin frame **101**.

If cursor **201** is not within margin frame **101**, system **120** constructs **603** a sphere **203**. In one embodiment, sphere **203** is not displayed on screen **127**, but is used for determination of the movement vector as follows. In one embodiment, sphere **203** has a center corresponding to the center of window **100** and a diameter such that the edge of sphere **203** touches each of the four inside borders of margin frame **101**. If window **100** is not square, a spheroid may be used in place of sphere **203**. In an alternative embodiment, sphere **203** is constructed having some other size and/or center point.

Referring again to FIG. **2**, the projection of sphere **203** onto window **100** forms a circle. If cursor **201** is not within the circle defined by the projection of sphere **203**, the movement vector is assigned **602** a z-value of zero, so that the viewpoint position will move parallel to the plane of the projection.

Referring again to FIGS. **3** and **6**, if cursor **201** is within the circle, system **120** constructs **605** a line **301** perpendicular to window **100** and passing through the point **202** defined by the location of cursor **201**. System **120** then determines **606** the intersections **302**, **303** of line **301** with the surface of sphere **203**. In general, two such intersections **302**, **303** will exist, one on each side of the x-y plane. The three-dimensional coordinates of these intersections can be represented as:

$$(\Delta x, \Delta y, \Delta z) = (x_{cursor}, y_{cursor}, \sqrt{2rm - m^2}) \quad \text{(Eq. 4)}$$

and

$$(\Delta x, \Delta y, \Delta z) = (x_{cursor}, y_{cursor}, -\sqrt{2rm - m^2}) \quad \text{(Eq. 5)}$$

where:

x_{cursor} and y_{cursor} are the coordinates of cursor **201** in window **100**;

r is the radius of sphere **203**; and

m is the distance between viewpoint position **204** and cursor **201**, such that

$$m = \sqrt{x_{cursor}^2 + y_{cursor}^2}.$$

System **120** then selects **607** one of the two intersections. If the z-axis points "out" of the display screen, the intersection **303** having a positive z-value represents backwards movement "out" of the screen, while the intersection **302** having a negative z-value represents forward movement "into" the screen. Thus, the selection of one of the two intersections is made based on the user's input regarding forward or backward movement. As described above, in one embodiment backward movement is indicated by holding a command or control key on keyboard **126**.

In the example of FIG. **3**, intersection **302** is selected, representing a negative z-value corresponding to forward motion "into" the screen. System **120** defines **608** movement vector **304** using the coordinates of intersection **302**. This movement vector **304** is then modified and applied as described above in connection with FIG. **5**.

In another embodiment, system **120** determines **504** a movement vector as (x, y, z), where x and y are the coordinates of cursor **201** in window **100**, and z is an arbitrary z-value that may be a predetermined constant, or may be user-configurable, or may be some linear or nonlinear function of x and y. z may be multiplied by −1 to indicate movement "out of" the window.

Referring again to FIG. **5**, system **120** modifies **505** the movement vector according to the modifier keys activated by the user, if appropriate. For example, if accelerated movement is indicated, system **120** multiplies the terms of the movement vector by some constant in order to increase its magnitude.

System **120** then adjusts **506** the viewpoint position **204** in the direction and magnitude specified by the movement vector. In one embodiment, this is accomplished by adding the terms of the movement vector to the coordinates of the viewpoint and assigning the result to the viewpoint.

As described above, in one embodiment of the present invention, the two-dimensional projection is generated using a scaling factor. When a scaling factor is used, nonlinear projection results, and thus it is advantageous to adjust the viewpoint position to preserve the illusion of three-dimensional movement in the desired direction. Specifically, when the user is moving in the direction of a particular object **102**, it is desirable that the apparent position of the object **102** in the two-dimensional projection remains stationary, or in an alternative embodiment, changes in a controlled manner by moving object **102** toward the center of the screen.

Referring now to FIG. **7**, there is shown a flowchart of a method of adjusting the viewpoint position to preserve the illusion of three-dimensional movement in the desired direction. System **120** identifies **701** which node, or on-screen object **102**, is closest to the center of window **100**. In an alternative embodiment, system **120** identifies a node that is closest to the cursor position. This "center node" is designated as N_C. System **120** then determines **702** the x and y coordinates of the center node in the two-dimensional projection of window **100**. These are designated as N_{Cx}, N_{Cy}. The viewpoint position in three-dimensional space before application of the movement vector is designated as (x_u, y_u, z_u). The movement vector is designated as (Δx, Δy, Δz). Thus, if linear projection is used, viewpoint position is updated **506** by adding the movement vector to the viewpoint position, so that:

$$x_{unew} = x_{uold} + \Delta x; \quad \text{(Eq. 6)}$$

$$y_{unew} = y_{uold} + \Delta y; \quad \text{(Eq. 7)}$$

$$z_{unew} = z_{uold} + \Delta z. \quad \text{(Eq. 8)}$$

If nonlinear projection is used, x_{unew} and y_{unew} are then adjusted as follows:

$$x_{uadj} = x_{unew} + \partial x; \quad \text{(Eq. 9)}$$

$$y_{uadj} = y_{unew} + \partial y; \quad \text{(Eq. 10)}$$

where ∂x, ∂y are selected such that N_{Cx}, N_{Cy} do not change, so that the apparent position of the center node on the screen remains constant.

System **120** determines ∂x by setting

$$N_{Cxold} = N_{Cxnew} \quad \text{(Eq. 11)}$$

and solving for ∂x. Thus, applying Eqs. 2 and 3,

$$N_{Cold} = (x_1 - x_u) f_{before}(1) + \sum_{m=2}^{n} x_m f_{before}(m); \quad \text{(Eq. 12)}$$

and

$$N_{Cnew} = (x_1 - x_u - \partial_x) f_{after}(1) + \sum_{m=2}^{n} x_m f_{after}(m). \quad \text{(Eq. 13)}$$

Setting these equal to each other, we obtain:

$$(x_1 - x_u) f_{before}(1) + \sum_{m=2}^{n} x_m f_{before}(m) = \quad \text{(Eq. 14)}$$

$$(x_1 - x_u - \partial_x) f_{after}(1) + \sum_{m=2}^{n} x_m f_{after}(m)$$

∂x can then be obtained by solving Eq. 14, so that:

$$\partial_x = x_1 - x_u - \frac{(x_1 - x_u) f_{before}(1) + \sum_{m=2}^{n} x_m f_{before}(m) - \sum_{m=2}^{n} x_m f_{after}(m)}{f_{after}(1)} \quad \text{(Eq. 15)}$$

If the scaling function of Eq. 1 is employed, we obtain:

$$\partial_x = x_1 - x_u - \frac{(x_1 - x_u)\frac{K}{l_{before}} \times \frac{1}{\sqrt{b_1}} + \sum_{m=2}^{n} x_m \left(\frac{K}{l_{before}} \times \sum_{p=1}^{m} \frac{1}{\sqrt{b_p}} \right) - \sum_{m=2}^{n} x_m \left(\frac{K}{l_{after}} \times \sum_{p=1}^{m} \frac{1}{\sqrt{b_p}} \right)}{\frac{K}{l_{after}} \times \frac{1}{\sqrt{b_1}}} \quad \text{(Eq. 16)}$$

which reduces to:

$$\partial_x = \left(1 - \frac{l_{after}}{l_{before}}\right)(x_1 - x_u) - \sqrt{b_1} \left(1 + \frac{l_{after}}{l_{before}}\right) \sum_{m=2}^{n} x_m \left(\prod_{p=1}^{m} \frac{1}{\sqrt{b_p}} \right). \quad \text{(Eq. 17)}$$

A similar technique is employed for determining ∂y, so that:

$$\partial_y = \left(1 - \frac{l_{after}}{l_{before}}\right)(y_1 - y_u) - \sqrt{b_1} \left(1 + \frac{l_{after}}{l_{before}}\right) \sum_{m=2}^{n} y_m \left(\prod_{p=1}^{m} \frac{1}{\sqrt{b_p}} \right)$$

For example, in FIG. **8**, if object **410** is located at (0, 0, 100); the viewpoint is located at (20, 0, 0); object **422** is located at (10, 0, 140); object **440** is located at (20, 0, 180); and the user moves the viewpoint forward to (20, 0, 50); the following values apply.

N_C, the center node, is object **440**;

l_{before}=distance to plane of object **410** before movement=100−0=100;

l_{after}=distance to plane of object **410** after movement=100−50=50;

x_1=x-position of object **410**=0;

x_2=x-position of object **422**=10;

x_3=x-position of object **440**=20;

x_u=x-position of viewpoint=20;

b_1=1+number of siblings of object **410**=1+0=1;

b_2=1+number of siblings of object **422**=1+3=4;

b_3=1+number of siblings of object **440**=1+3=4.

Thus,

$$\partial_x = \left(1 - \frac{50}{100}\right)(0 - 20) - \sqrt{1} \left(1 + \frac{50}{100}\right)\left(10 \frac{1}{\sqrt{1}} \frac{1}{\sqrt{4}} + 20 \frac{1}{\sqrt{1}} \frac{1}{\sqrt{4}} \frac{1}{\sqrt{4}}\right) \quad \text{(Eq. 19)}$$

$$= -10 - (1.5)(5 + 5)$$

$$= -25.$$

Therefore, in order to preserve the illusion of movement toward object **440** by maintaining its position in the two-dimensional projection, the viewpoint position is moved along the x-axis by −25. Assuming no adjustment is made along the y-axis, the final position for the viewpoint is (20-25, 0, 50), or (−5, 0, 50).

Referring again to FIG. **5**, after adjusting **506** viewpoint position, system **120** displays **507** a new two-dimensional projection based on the adjusted viewpoint position **204**.

Referring now also to FIG. **4**, there is shown an updated front view of window **100** given the starting viewpoint position of FIG. **2** and some degree of movement in the direction indicated by cursor **201**.

Referring again to FIG. **5**, the user may indicate that continued or additional movement is desired by holding down the mouse button. If additional movement is indicated **508** after the new projection is displayed, system **120** returns to **502** to obtain a new cursor **201** position. If desired, the user may move cursor **201** to another location in window **100**, in which case the movement vector will be modified accordingly.

In some applications, system **120** may provide functionality allowing the user to activate and/or move some or all of on-screen objects **120**. It then becomes useful to distinguish between user actions specifying viewpoint movement and user actions specifying manipulation or activation of on-screen objects **120**. In one embodiment wherein mouse **125** has more than one button, different mouse buttons may be used to represent different actions. For example, a first mouse button may be used to specify viewpoint movement, while a second mouse button may be clicked to activate an object **120** or held down while dragging mouse **125** to move an object **120**. In another embodiment, the two functions may be specified by holding down modifier keys on keyboard **126**.

In another embodiment, all such functions are implemented using a single mouse button. The desired operation is determined based on the context and nature of the user's action. Thus, if the user positions cursor **201** over an object **120** and clicks the mouse button briefly, object **120** is opened or activated, depending on the nature of object **120**. If the

user positions cursor **201** over an object **120**, clicks and holds the mouse button, and immediately starts dragging cursor **201** to another position, object **120** is moved accordingly. If the user clicks and holds the mouse button for some period of time without substantially changing the position of cursor **201**, system **120** interprets the command as a navigation command and moves viewpoint position **204** to simulate movement through the three-dimensional space. Thus, when the mouse button is pressed, system **120** waits some interval of time before commencing movement, in order to determine whether the user intends to drag an on-screen object **102** or move the viewpoint position **204**. In one embodiment, this time interval is 0.5 seconds, though other time intervals may be used, and user configuration of the time interval may be permitted. In one embodiment, some small amount of cursor **201** movement is permitted without activating object **120** movement, and user configuration of this "tolerance" amount may be permitted as well.

In one embodiment, if the user clicks the mouse button while cursor **201** is not positioned over any object **102**, viewpoint position movement commences immediately, since there is no ambiguity as to the intended action.

The above description provides merely exemplary embodiments for practicing the present invention. Those skilled in the art will recognize that other embodiments are possible without departing from the spirit or essential elements of the invention claimed herein.

What is claimed is:

1. A method for displaying movement through a virtual three-dimensional space, comprising:

a) determining a viewpoint position in the three-dimensional space;

b) displaying a two-dimensional projection of the three-dimensional space onto a plane, based on the viewpoint position;

c) identifying a point on the plane;

d) identifying a destination position in the three-dimensional space based on the identified point on the plane;

e) moving the viewpoint position in the direction of the destination position; and

f) displaying a two-dimensional projection of the three-dimensional space based on the moved viewpoint position.

2. The method of claim **1**, wherein c) comprises determining a position of an on-screen cursor.

3. The method of claim **1**, wherein d) comprises:

d.1) defining a sphere having a center corresponding to the viewpoint position; and

d.2) determining a point on the sphere being the intersection of a line perpendicular to the plane and intersecting the identified point on the plane.

4. The method of claim **1**, wherein the identified point has an x-coordinate and a y-coordinate, and wherein d) comprises identifying a destination position having three-dimensional coordinates selected from one of $(x_{cursor}, y_{cursor}, \sqrt{2rm-m^2})$ and $(x_{cursor}, y_{cursor}, -\sqrt{2rm-m^2})$, where x_{cursor} represents the x-coordinate of the identified point and y_{cursor} represents the y-coordinate of the identified point.

5. The method of claim **1**, further comprising:

b.1) defining a z-axis perpendicular to the plane having a positive direction and a negative direction; and

c.1) identifying one of the positive and negative z-axis directions for movement;

and wherein d) comprises:

d.1) defining a sphere having a center corresponding to the viewpoint position; and

d.2) determining a point on the sphere being the intersection of a line parallel to the z-axis, originating at the identified point on the plane, and constructed in the z-axis direction identified in c.1).

6. The method of claim **5**, wherein c.1) comprises determining a position of a key on a keyboard.

7. The method of claim **1**, wherein the viewpoint position has an x-coordinate and a y-coordinate, and wherein d) comprises identifying a destination position having x- and y-coordinates corresponding to the x- and y-coordinates of the viewpoint position, and having a z-coordinate corresponding to a predetermined value.

8. The method of claim **1**, wherein the viewpoint position has an x-coordinate and a y-coordinate, and wherein d) comprises identifying a destination position having x- and y-coordinates corresponding to the x- and y-coordinates of the viewpoint position, and having a z-coordinate derived by applying a function to the values of the x- and y-coordinates.

9. The method of claim **1**, wherein b) comprises displaying the two-dimensional projection in a window having a frame and a center, the frame comprising at least two opposing sides, each opposing side comprising a midpoint, the frame representing at least a portion of the plane, and wherein d) comprises:

d.1) defining a sphere having a center corresponding to the center of the window and a point of tangency with each midpoint of two opposite sides of the frame; and

d.2) determining a point on the sphere being the intersection of a line perpendicular to the plane and intersecting the identified point on the plane.

10. The method of claim **1**, further comprising:

c.1) specifying a movement speed;

and wherein:

a) comprises determining a viewpoint position in the three-dimensional space, the viewpoint position defined by an x-coordinate, a y-coordinate, and a z-coordinate;

d) comprises identifying a destination position defined by an x-coordinate, a y-coordinate, and a z-coordinate; and

e) comprises adjusting the x-coordinate, y-coordinate, and z-coordinate of the viewpoint position by a specified amount based on the specified movement speed, to move the viewpoint position in the direction of the destination position.

11. The method of claim **10**, wherein c.1) comprises determining a position of a switch.

12. The method of claim **10**, wherein b) comprises displaying a linear two-dimensional projection.

13. The method of claim **10**, wherein b) comprises displaying a nonlinear two-dimensional projection.

14. The method of claim **13**, wherein the three-dimensional space contains at least one object, the object having an initial position in the two-dimensional projection, the method further comprising:

e.1) designating one of the at least one objects; and

e.2) further adjusting the coordinates of the viewpoint position to maintain the initial position of the object in the two-dimensional projection.

15. The method of claim **1**, further comprising:

c.1) detecting an input signal specifying a movement command.

16. The method of claim **15**, wherein c.1) comprises detecting that a button is pressed.

17. The method of claim 15, wherein c.1) comprises detecting that a button is held for a predetermined length of time.

18. The method of claim 15, wherein:

c) comprises detecting a position of an on-screen cursor controlled by a mouse having a button;

c.1) comprises detecting that the mouse button is held for a predetermined length of time while the on-screen cursor remains substantially stationary.

19. The method of claim 18, wherein the predetermined length of time is sufficiently long to distinguish the movement command from an object manipulation command.

20. The method of claim 1, wherein the three-dimensional space contains at least one object, at least one of the objects representing a document.

21. A computer program product comprising a computer-usable medium having computer-readable code embodied therein for displaying movement through a virtual three-dimensional space, comprising:

computer-readable program code devices configured to cause a computer to determine a viewpoint position in the three-dimensional space;

computer-readable program code devices configured to cause a computer to display a two-dimensional projection of the three-dimensional space onto a plane, based on the viewpoint position;

computer-readable program code devices configured to cause a computer to identify a point on the plane;

computer-readable program code devices configured to cause a computer to identify a destination position in the three-dimensional space based on the identified point on the plane;

computer-readable program code devices configured to cause a computer to move the viewpoint position in the direction of the destination position; and

computer-readable program code devices configured to cause a computer to display a two-dimensional projection of the three-dimensional space based on the moved viewpoint position.

22. The computer program product of claim 21, wherein the computer-readable program code devices configured to cause a computer to identify a destination position comprise:

computer-readable program code devices configured to cause a computer to define a sphere having a center corresponding to the viewpoint position; and

computer-readable program code devices configured to cause a computer to determine a point on the sphere being the intersection of a line perpendicular to the plane and intersecting the identified point on the plane.

23. The computer program product of claim 21, wherein the viewpoint position has an x-coordinate and a y-coordinate, and wherein the computer-readable program code devices configured to cause a computer to identify a destination position comprise computer-readable program code devices configured to cause a computer to identify a destination position having x- and y-coordinates corresponding to the x- and y-coordinates of the viewpoint position, and having a z-coordinate derived by applying a function to the values of the x- and y-coordinates.

24. The computer program product of claim 21, further comprising:

computer-readable program code devices configured to cause a computer to specify a movement speed;

and wherein:

the computer-readable program code devices configured to cause a computer to determine a viewpoint position comprise computer-readable program code devices configured to cause a computer to determine a viewpoint position in the three-dimensional space, the viewpoint position defined by an x-coordinate, a y-coordinate, and a z-coordinate;

the computer-readable program code devices configured to cause a computer to identify a destination position in the three-dimensional space comprise computer-readable program code devices configured to cause a computer to identify a destination position defined by an x-coordinate, a y-coordinate, and a z-coordinate; and

the computer-readable program code devices configured to cause a computer to move the viewpoint position in the direction of the destination position comprise computer-readable program code devices configured to cause a computer to adjust the x-coordinate, y-coordinate, and z-coordinate of the viewpoint position by a specified amount based on the specified movement speed, to move the viewpoint position in the direction of the destination position.

25. The computer program product of claim 24, wherein the three-dimensional space contains at least one object, the object having an initial position in the two-dimensional projection, and wherein the computer-readable program code devices configured to cause a computer to display a two-dimensional projection of the three-dimensional space onto a plane comprise computer-readable program code devices configured to cause a computer to display a nonlinear two-dimensional projection, the computer program product further comprising;

computer-readable program code devices configured to cause a computer to designate one of the at least one objects; and

computer-readable program code devices configured to cause a computer to further adjust the coordinates of the viewpoint position to maintain the initial position of the object in the two-dimensional projection.

26. The computer program product of claim 21, wherein the computer-readable program code devices configured to cause a computer to identify a point on the plane comprise computer-readable program code devices configured to cause a computer to detect a position of an on-screen cursor controlled by a mouse having a button, the computer program product further comprising:

computer-readable program code devices configured to cause a computer to detect that a button is pressed and held for a predetermined length of time while the on-screen cursor remains substantially stationary, to specify a movement command, the predetermined length of time being sufficiently long to distinguish the movement command from an object manipulation command.

27. An apparatus for displaying movement through a virtual three-dimensional space, comprising:

a memory module for storing a viewpoint position in the three-dimensional space;

a display device, coupled to the memory module, for displaying a two-dimensional projection of the three-dimensional space onto a plane, based on the viewpoint position;

an input device, coupled to the memory module, for identifying a point on the plane;

a destination position identifier, coupled to the memory module, for identifying a destination position in the

three-dimensional space based on the identified point on the plane; and

a viewpoint position mover, coupled to the memory module for moving the viewpoint position in the direction of the destination position;

wherein the display device further displays a two-dimensional projection of the three-dimensional space based on the moved viewpoint position.

28. The apparatus of claim **27**, wherein the destination position identifier defines a sphere having a center corresponding to the viewpoint position and determines a point on the sphere being the intersection of a line perpendicular to the plane and intersecting the identified point on the plane.

29. The apparatus of claim **27**, wherein the viewpoint position has an x-coordinate and a y-coordinate, and wherein the destination position identifier identifies a destination position having x- and y-coordinates corresponding to the x- and y-coordinates of the viewpoint position, and having a z-coordinate derived by applying a function to the values of the x- and y-coordinates.

30. The apparatus of claim **27**, wherein:

the input device further specifies a movement speed;

the stored viewpoint position is defined by an x-coordinate, a y-coordinate, and a z-coordinate;

the identified destination position is defined by an x-coordinate, a y-coordinate, and a z-coordinate; and

the viewpoint position mover adjusts the x-coordinate, y-coordinate, and z-coordinate of the viewpoint position by a specified amount based on the specified movement speed, to move the viewpoint position in the direction of the destination position.

31. The apparatus of claim **30**, wherein:

the three-dimensional space contains at least one object, the object having an initial position in the two-dimensional projection;

the display device displays a nonlinear two-dimensional projection; and

the viewpoint position mover designates one of the at least one objects and further adjusts the coordinates of the viewpoint position to maintain the initial position of the object in the two-dimensional projection.

32. The apparatus of claim **27**, wherein the input device comprises a mouse having a button for controlling an on-screen cursor, and wherein the input device detects that the button is pressed and held for a predetermined length of time while the on-screen cursor remains substantially stationary, to specify a movement command, the predetermined length of time being sufficiently long to distinguish the movement command from an object manipulation command.

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